DEVELOPMENT OF A DIGITAL PEAK VOLTMETER FOR THE MEASUREMENT OF POWER FREQUENCY HIGH VOLTAGE

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by
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TO

MY PARENTS

BROTHER

AND

SISTERS

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ABSTRACT

In this thesis high voltage measurement techniques at power frequency have been studied. Both conventional and modern techniques used for high voltage and current measurement are reviewed.

A Digital Peak Voltmeter has been designed, developed and fabricated using capacitive voltage divider principle. The instrument has also been tested and calibrated to measure 0-100 kV through a high voltage capacitor. The calibration of the instrument developed is achieved using a standard capacitive divider.

CONTENTS

LIST OF PRINCIPAL SYMBOLS

A/D	: Analogue to digital
U,V	: Voltage
D/A	: Digital to analogue
DPM	: Digital panel meter
EMI	: Electromagnetic interference
RI	: Radio interference
LED	: Light emitting diode
PD	: Photo diode
OP AMP	: Operational amplifier

Chapter 1

INTRODUCTION

The demand for the generation of large amount of electric power today, necessitates its transmission at Ultra high voltages. In countries like USA and USSR, power transmission voltages have reached 1150 kV level and 1500 kV system is under development.

In order to exhaust the bulk power generated at pit heads and at large hydro electric sources to the far distant load centres, the only economic way is to go for these higher voltages. The concentration of loads has required to bring higher voltages near the load centres and thus raise also the distribution voltage levels considerably.

It has been a challenging task for the engineers to develop suitable insulation and control systems for these voltages. Insulation system must be economic and reliable. The diverse conditions under which a high voltage apparatus is used necessitate careful design of its insulation and the electrostate field profiles, The principal media of insulation used are gases, vacuum, solid and liquid, or a combination of these. For achieving reliability and economy, a knowledge of the causes of deterioration is essential, and the tendency to

increase the voltage stress for optimum design call for judicious selection of insulation in relation to the dielectric strength, partial discharges and other relevant factors.

For the research, development, quality control and continuous monitor and control of the substation equipment and the system, cheaper, reliable and accurate techniques are desired for the measurement of electrical quantities, for example, voltage, current, power factor etc. For the estimation of actual electric stress on the dielectrics, knowledge of peak value of voltage applied is important. The applied sinusoidal waveform may get distorted due to harmonic currents, high capacitive loads or due to poor saturation characteristics of the transformer. The rms value, commonly measured from the low voltage side of a HV transformer may therefore not be equal to $1/\sqrt{2}$ times the peak value. But the stress on the dielectric is determined by the peak value. Thus the rms value measured may not give correct estimation of electric field applied to the dielectric. The knowledge of peak value of the voltage applied on the dielectric is therefore essential.

For the design and testing of high voltage apparatuses like transformers, cable,bushing etc a well equipped laboratory to cater the need for UHV ranges is required in Northern region of our country where no such facility exists/1/. The need of

such a laboratory was long felt and it is due to this need that a laboratory is being developed at I.I.T. Kanpur. In our laboratory we have 100 kV partial discharge free testing transformer along with a 100kV coupling/measuring capacitor. We have other very important instruments like Partial Discharge Measuring instrument, Schering bridge and oil testing set. For voltage measurement we have meters in the control panel which measure the rms voltage from primary side. There was a need of a power frequency AC Peak Voltmeter suitable for the measurement of peak value of this testing transformer voltage over the measuring capacitor, working as the Capacitive Voltage divider. Development of such a digital peak voltmeter has been taken up in this project work.

In chapter 2, conventional methods for the measurement of power frequency high voltage have been reviewed. Direct and Indirect methods of measurement have been studied separately. Different peak value measuring circuits are examined and their accuracy, improvements, and performance discussed.

In chapter 3, the possibility of use of Fibre Optics for the measurement of voltage and current at high voltage levels have been studied. Both the measurement techniques, using active devices and passive sensors have been studied separately. Though little work has so far been done for the

measurement of high voltage as compared to the measurement of current using active sensors, still the possibility of using same current measurement techniques for the measurement of high voltage have been examined.

In chapter 4, complete design and development of the Digital Peak Voltmeter for the measurement of power frequency high voltage using capacitive voltage divider principle and a coaxial cable has been given.

The main features of the instrument regarding its application and utility have been discussed besides the different protection schemes incorporated in the instrument. The testing and calibration of this instrument taken up in the HV laboratory of the department has been explained.

Chapter 2

MEASUREMENT OF HIGH POWER FREQUENCY VOLTAGE

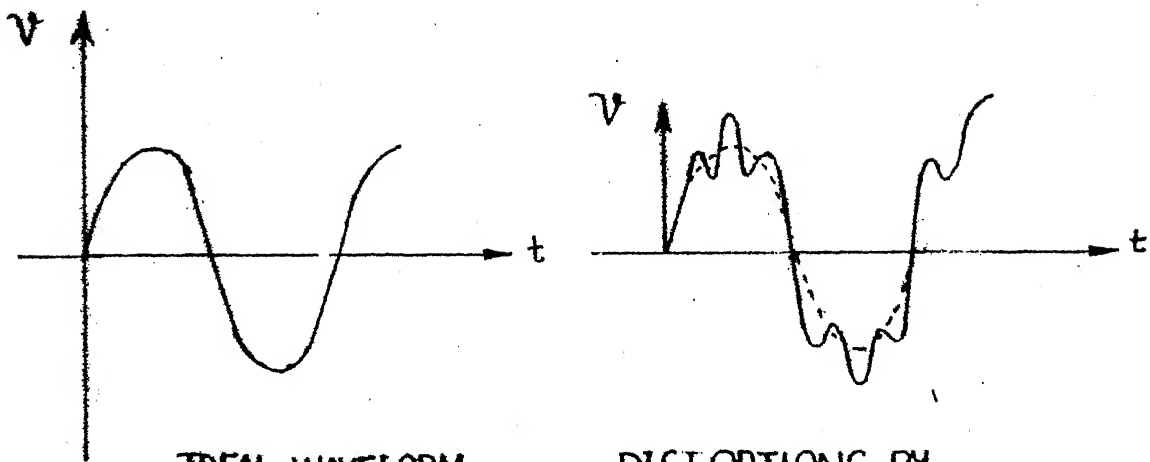
2.1 INTRODUCTION

In this chapter conventional techniques which are being used for high voltage measurements have been described. Both direct and indirect methods of high voltage power frequency measurements, besides various techniques for the measurement of effective or rms and the peak value are examined and their range of application and accuracy have been discussed.

2.2.1 Necessity of the Measurement of Peak Voltage

The output voltage of testing transformer, that is the voltage to be measured, should ideally have a sinusoidal waveform. In some cases it has been observed that ideal waveform is not achieved, if the electrical load on a transformer is a polluted test model, test model with high capacitance or if there are predischarges at the test object. Harmonic waves and internal voltage drops can be the reasons for distortions in the ideal waveform of output voltage as shown in Fig. 2.1.

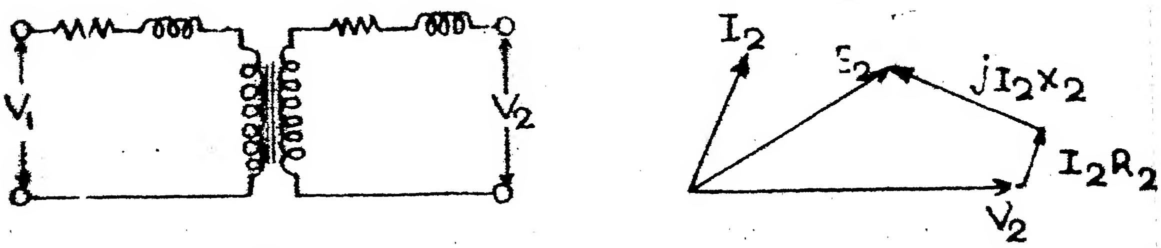
In such cases, the relation between the peak value and the rms value is not given by the factor $\sqrt{2}$. Under these conditions, it is highly desired to know the peak value of the voltage applied to the test object because of its importance on the breakdown of insulating materials at power frequency.



IDEAL WAVEFORM

DISTORTIONS BY HARMONIC WAVES

FIG 2.1



(a) (b)

FIG.2.2

2.2.2 Measurement of Voltage from the Secondary Side of the Testing Transformer

The high voltage applied on a test object is generally measured from the low voltage side, that is the primary side. But it is always advisable to measure the voltage from the secondary side of the transformer especially in the case of cable or for high capacitive load testing.

Normally in this arrangement, the high voltage is measured from the primary side by taking into account the turns ratio under open circuit operation of the transformer. But even under no load operation this ratio is not completely true for the terminal voltages. It is exactly true only for the primary and secondary induced voltages E_1 and E_2.

Most high-voltage test objects - Cable, post insulators, bushings and so on-represent primarily capacitive loads and furthermore, the coil and stray ground capacitances of the secondary winding exhibit a considerable capacitive load even under open circuit operation. In contrast to inductive loads, capacitive loads cause an increase of the high voltage.

Fig. 2.2 show the circuit and the phasor diagram of a transformer with capacitive load current. It is clear from the figure that the voltage measured from primary side (V_1) will be

less than actual applied high voltage on the test object (V_2). Thus there exists a danger of actually stressing the object at higher voltage than it may be shown by the measurement from the primary side of the HV test transformer.

2.3 METHODS OF HIGH VOLTAGE MEASUREMENT

The methods of measurement of high power frequency voltage are classified [2] as following :

The direct methods are :

(a) Electrostatic voltmeter

(b) Sphere Air Gap

And the indirect methods are :

(a) Voltage Divider

(b) Transformation of the voltage.

The actual waveform of the output voltage can be known by means of an oscilloscope.

2.3.1 Direct Measurement of Voltage

2.3.1.1 Electrostatic voltmeter

In electrostatic fields, the attractive force between the electrodes of a parallel plate condenser is given by [3]

$$F = \left| \frac{-\delta W_s}{dS} \right| = \left| \frac{\delta}{\delta S} \left(\tfrac{1}{2} CV^2 \right) \right| = \left| \tfrac{1}{2} V^2 \frac{\delta C}{\delta S} \right|$$

$$= \tfrac{1}{2} \varepsilon_o V^2 \frac{A}{S^2} = \tfrac{1}{2} \varepsilon_o A \left(\frac{V}{S} \right)^2 \qquad (2.1)$$

where, V = applied voltage between plates

C = capacitance between plates

A = area of cross section of the plates

S = separation between the plates

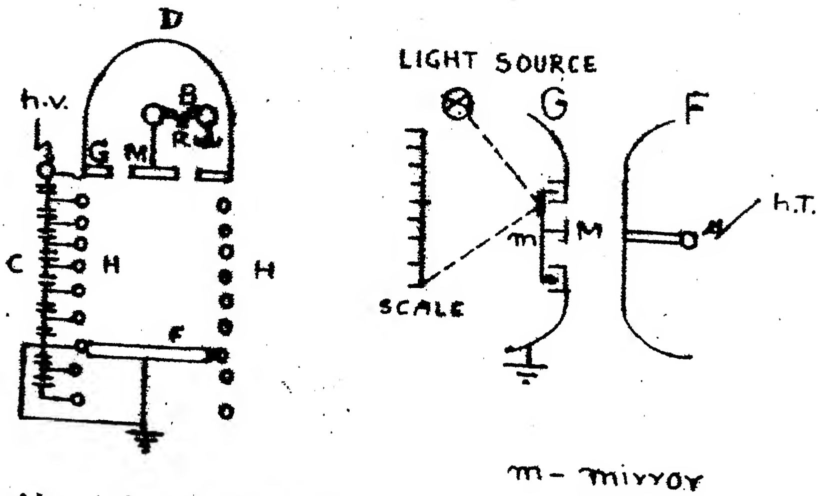
ε_o = permittivity of the medium (air or free space)

W_s = work done in displacing a plate

When one of the electrodes is free to move, the force on the plate can be measured by controlling it by a spring or balancing it with a counter weight. For high voltage measurements, a small displacement of one of electrode by a fraction of a millimeter to a few millimeters is usually sufficient for voltage measurements. As the force is proportional to the square of applied voltage, the measurements can be made for ac or dc voltages.

Construction

Electrostatic voltmeters are made with parallel plate configuration using guard rings to avoid corona and field fringing at the edges. An absolute voltmeter is made by balancing the plate with a counter weight and is calibrated in terms of a small weight. Usually the electrostatic voltmeters have a small capacitance (5 to 50 pF) and high insulation resistance ($R \geqslant 10^{13}\ \Omega$). Hence they are considered as device with high input impedance. The upper frequency limit for ac



(a) Absolute electrostatic Voltmeter (b) Light beam arrangment

M — Mounting Plate
G — Guard Plate
F — Fixed Plate
H — Guard loops or rings
B — Balance
C — capacitance divider
D — Dome
R — Balancing weight

FIG 2.3

applications is determined from the following consideration :

(i) natural frequency of the moving system,

(ii) resonant frequency of the lead and stray inductances with meter capacitance, and

(iii) the R-C behaviour of the retaining or control spring (due to the frictional resistance and elastance).

An upper frequency limit of about one MHz is achieved in careful designs. The accuracy for ac voltage measurements is better than $\pm$ 0.25 and for dc voltage measurements it may be $\pm$ 0.1% or less.

The schematic diagram of an absolute electrostatic voltmeter is shown in Fig. 2.3. It consists of parallel plane disc type electrodes separated by a small distance. The moving electrode is surrounded by a fixed guard ring to make the field uniform in the central region. In order to measure the given voltage with precision, the disc diameter is to be increased, and the gap distance is to be made less. The limitation on the gap distance is the safe working stress ($V/_S$) allowed in air which is normally 4 $kV/_{cm}$ or less. The main difference between several forms of voltmeter lies in the manner in which the restoring force is obtained. In conventional version of meters, a simple spring control is used. In more versatile instruments, only small movements of the moving electrode is

allowed, and the movement is amplified by optical means (lamp and scale arrangement as used with moving coil galvanometers). Two air vane dampers are used to reduce vibrational tendencies in the moving system, and the elongation of the spring is kept minimum to avoid field disturbances. The range of the instrument is easily changed by changing the gap separation so that V/S or electric stress is the same for the maximum value in any range. Multirange instruments are constructed for 600 kV rms and above.

The constructional details of an absolute electrostatic voltmeter is given in Fig. 2.3 a. The control torque is provided by a balancing weight. The moving disc M forms the central core of the guard rings G which is of same diameter as the fixed plate F. The cap D encloses a sensitive balance B, one arm of which carries the suspension of the moving disc. The balance beam carries a mirror which reflects a beam of light. The movement of disc is thereby magnified. As the spacing between the two electrodes is large, the uniformity of the electric field is maintained by guard ring H which surround space between the discs F and M. The guard rings H are maintained at a constant potential in space by a capacitance divider ensuring a uniform special potential distribution.

some instruments are constructed in an enclosed structure containing compressed air, carbon dioxide, or nitrogen. The gas pressure may be of the order of 15 atm. Working stress as high as 100 kV/cm may be used in an electrostatic meter in vacuum. With compressed gas or vacuum as medium, the meter is compact and much smaller in size. This instrument is a delicate instrument. So it should be handled carefully.

2.3.1.2 Measuring sphere air gap

A uniform field spark gap will always have a sparkover voltage within a known tolerance under constant atmospheric conditions. Hence a spark gap can be used for measurement of the peak value of the voltage, if the gap distance is known A sparkover voltage of 30 kV (peak) at 1 cm spacing in air at $20^{\circ}C$ and 760 torr pressure occurs for a sphere gap or any uniform field gap. But experience has shown that these measurements are reliable only for certain gap configurations. Normally only sphere gaps are used for voltage measurements. In certain cases uniform field gaps and rod gaps are also used, but their accuracy is less. The sphere gap breakdown is independent of the voltage waveform and hence is highly suitable for all types of waveform from dc to impulse voltage. As such, sphere gaps can be used for radio frequency ac voltage peak measurements also (upto 1 MHz).

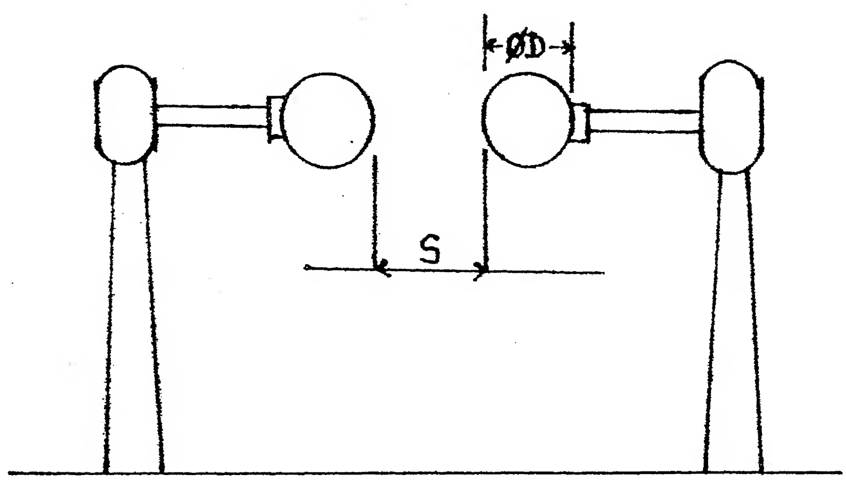


FIG. 2.4. SPHERE AIR GAP

Sphere Gap Measurements

Sphere gap can be arranged [3] either (i) vertically with lower sphere grounded or (ii) horizontally with both spheres connected to the source voltage or one sphere grounded. The two sphere are identical in size and shape. The schematic arrangement is shown in Fig. 2.4.

A series resistance is usually connected between the source and the sphere gap to (i) limit the breakdown current, and (ii) to suppress unwanted oscillations in the source voltage when breakdown occurs. The value may vary from 100 to 1000 KΩ . The breakdown between the spheres indicates that the electric field strength 'E' has exceeded the dielectric strength of the air gap. The magnitude of the applied voltage can be determined from the calibration curves. The curves show the breakdown voltage as a function of the distance between the spheres. Calibration curves for different sphere diameters are available. The sphere gaps are suitable as they are simple in construction, operation and require minimum maintenance. They are robust which is very important for the use in HV laboratories . The peak value of the applied voltage, which is important for a short-time breakdown at 50 Hz can be read out from the calibration. Thereby, the distortion in the voltage are taken into account.

Disadvantages [3] of this method of voltage measurements are :

(a) the noncontinuous measurement,

(b) it is not possible to measure the breakdown voltage of a test object directly, and

(c) low accuracy and inconvenience due to tables and constants to be considered.

The use of sphere gap may lead to an error of upto $\pm$ 3 %. The accuracy of the measurements depend upon the following :

I. With regard to the construction of the spheres :

a. smoothness of the metallic surface

b. deviation of the diameter (it should not be more than 1%).

c. accuracy in the measurement of the distance between the sphere it must be determined with an accuracy of 0.5 %

II. With regard to the use

a. in order to ensure that wall, equipment etc. do not influence the breakdown voltage, the distance to neighbouring objects should not be less than 3 to 7D (D is the diameter of sphere).

b. The distance between the spheres should be such that

$$S < \frac{D}{2}$$

For greater distances, the homogeneity of the electric field will be too low.

c. If the atmospheric conditions deviate from the normal values (760 Torr, 20°C) correction in the breakdown voltage must be made according to the tables given in the literatures. If the breakdown or sparkover voltage is V under test conditions of temperature T and pressure P torr and if the sparkover voltage is V_o under standard conditions of temperature 20°C and pressure p = 760 torr, then

$$V = k\,V_o$$

where K is a function of the air density factor d, given by [3]

$$d = \frac{p}{760}\;\frac{293}{273+T}$$

The relationship between d and K is given in Table 2.1.

Table 2.1 Relation between Correction Factor K and Air Density Factor d

d	0.70	0.75	0.80	0.85	0.90	0.95	1.0	1.05	1.10	1.15
k	0.72	0.77	0.82	0.86	0.91	0.95	1.0	1.05	1.09	1.12

The sparkover voltage increases with humidity for non uniform gaps [4]. The increase is about 2 to 3% over normal

humidity range of 8 g/m^3 to 15 g/m^3. Since the change is within 3 % no correction is normally given for humidity.

2.3.2 Indirect Measurement of Voltage

Indirect measurement of the voltage means; the measurement of essentially a low voltage or a current, the magnitude of which depends upon the actual value of the voltage applied to the test object in a predetermined ratio.

There are five methods [2] of indirect measurements of high voltage.

(I) Voltage divider with a Resistor,

(II) Measurement of current through a measuring resistor,

(III) Voltage Divider with capacitors,

(IV) Measurement of voltage at the low voltage winding of transformer, and

(V) Measurement of voltage across a definite Tapping at the high voltage winding of testing transformer

First we will consider only effective or rms value measurement. The measurement of the peak value will be considered later.

2.3.2.1 Resistive voltage divider

A resistive voltage divider (Fig.2.5) consists of a higher voltage resistor R_1, which must be designed for the rated high voltage, and a lower voltage resistor R_2. The ratio of

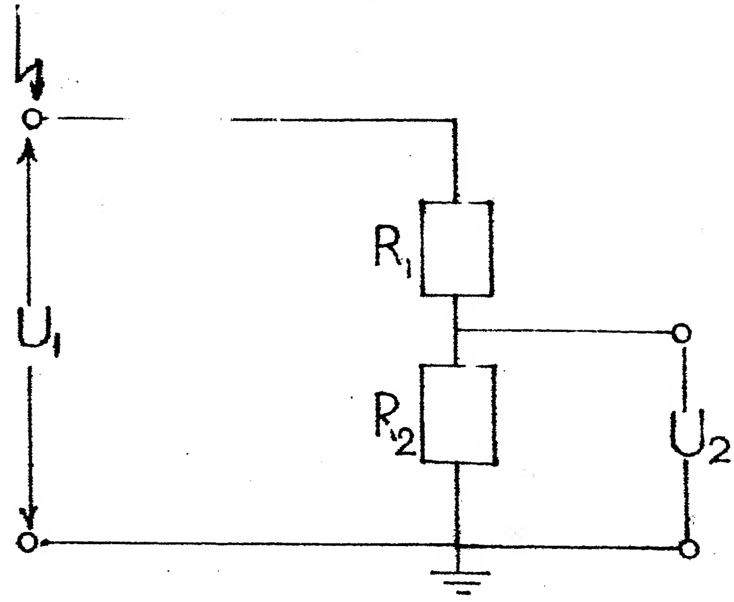


FIG.2.5. RESISTIVE VOTAGE DIVIDER

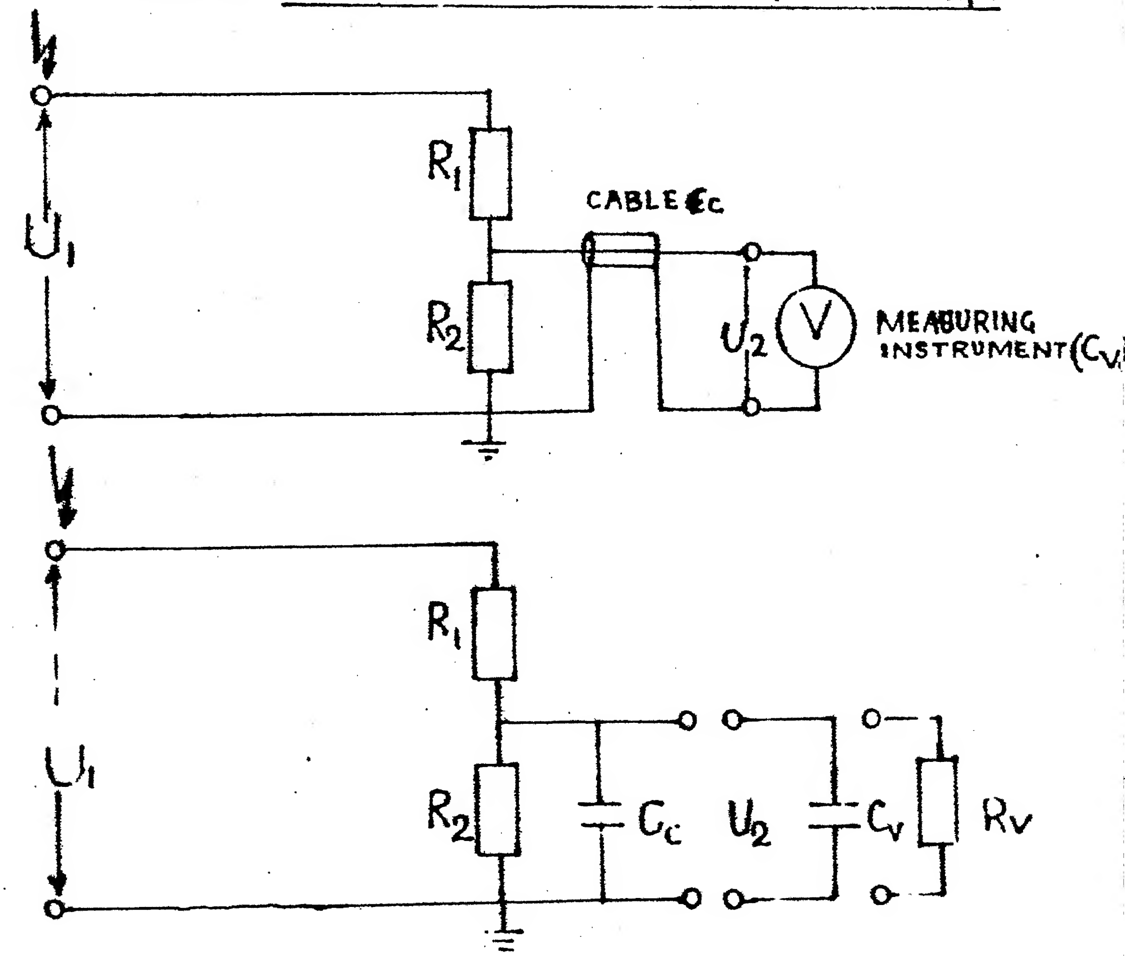


FIG.2.6.

the voltage division is given by [2]

$$\frac{U_1}{U_2} = \frac{R_1 + R_2}{R_2} \quad , \quad R_1 \gg R_2$$

In practice, the capacitance of the cable connecting the lower voltage arm to the measuring instrument and that of the measuring instrument itself (electrostatic voltmeter) and the resistance of the instrument (moving coil instrument) must also be considered Fig. 2.6.

with C_v :

$$\frac{U_1}{U_2} = \frac{R_1 + R_2 + jwR_1R_2\,(C_c + C_v)}{R_2}$$

for low frequencies and low capacitances of C_c and C_v

$$R_1 + R_2 \gg w\,R_1R_2\,(C_c + C_v)$$

with R_v :

$$\frac{U_1}{U_2} = \frac{R_1R_v + R_2R_v + R_1R_2\,(1+jC_cR_v)}{R_2R_v}$$

for low frequencies and low capacitance of C_c

$$1 \gg wC_cC_vR_v$$

and because R_1 and $R_v \gg R_2$ the ratio in both the cases can be expressed as

$$\frac{U_1}{U_2} = \frac{R_1 + R_2}{R_2}$$

For extra high voltage ($U \geq 1MV$) the safety distance must be kept very large. That means, the cable between the lower voltage part and the measuring instrument will be very long and the cable capacitance will be significant, e.g. a cable which is 15 m long and has a capacitance of 75 pF per meter. The total capacitance will be

$$C_c = 1.125 \text{ nF}, \; f = 50 \text{ Hz}$$

so $$X_c = \frac{1}{\omega C_c} \simeq 2.8 \text{ M}\Omega$$

To minimise the losses, the total resistance of the devider must be very high. That means, for a predetermined ratio the value of R_2 must be also high. Therefore, the effect of cable capacitance or resistance of the measuring instrument on the division ratio can be considerable. Moreover, the division ratio varies with frequency.

These are the reason why resistive voltage dividers are rarely used for the measurement of high power frequency voltage.

2.3.2.2 Measurement of current through a measuring resistor

The arrangement [2] is shown in Fig. 2.7. In the Fig. the resistance R_m is approx. of the order of R_1 (Fig. 2.5). Since $R_m \gg R_A$, the dependence of current I on the low voltage side resistance R_A(which may change with change in measuring range) is negligible. Usually the ammeter used is a moving

coil instrument. The applied high voltage can be determined with the help of calibration curves or calculation factor as function of the current I.

2.3.2.3 Capacitive voltage divider

Capacitive voltage dividers are the most accurate and widely used divider for the measurement of high power frequenc voltage [2].

A capacitive voltage divider consists of a high voltage capacitance C_1, which must be designed for the high voltage, and a lower voltage capacitance C_2. The voltage division rati of this ideal voltage divider (Fig. 2.8) is given by

$$\frac{U_1}{U_2} = \frac{C_1 + C_2}{C_1} \text{, where } C_1 \ll C_2$$

In practice, the effect of electrical parameters of the connecting cable and that of the measuring instrument on divis ratio must be considered. (Fig. 2.9).

From Fig. 2.9, the respective division ratios are given as

with C_v:

$$\frac{U_1}{U_2} = \frac{C_1 + C_2 + C_v + C_2}{C_1}$$

with R_v:

$$\frac{U_1}{U_2} = \frac{1 + j\,wR_v(C_1 + C_2 + C_c)}{jwR_vC_1}$$

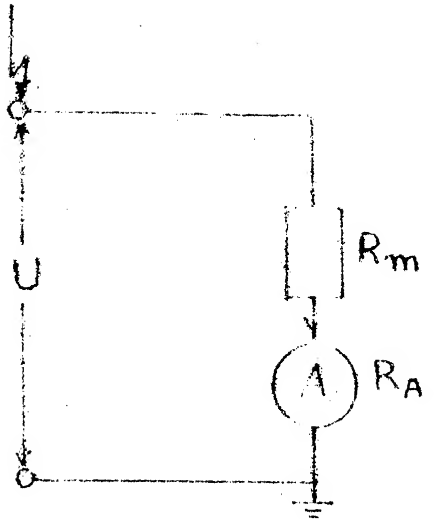


FIG. 2.7 MEASURING RESISTER

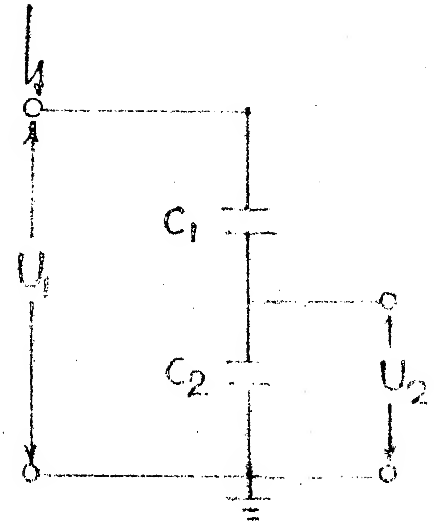
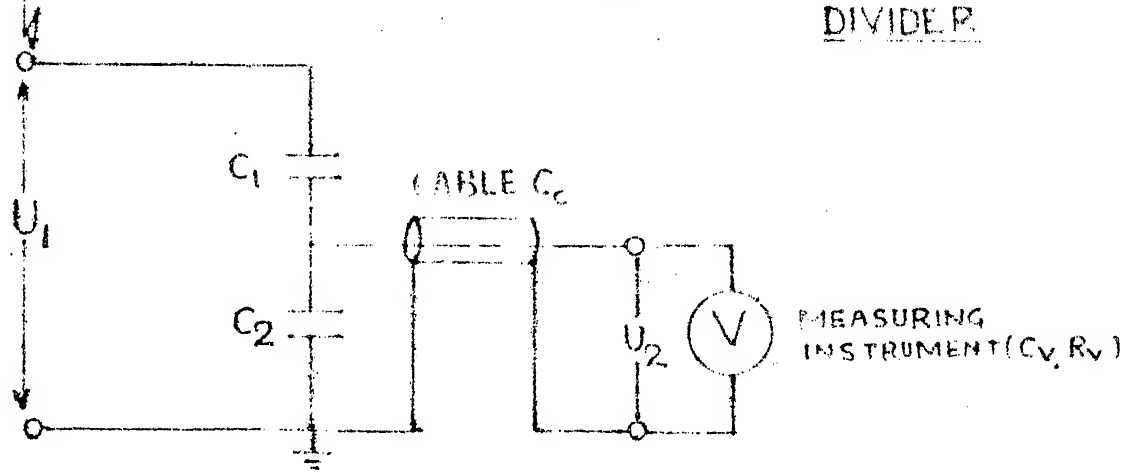


FIG.2.8 CAPACITIVE VOLTA DIVIDER



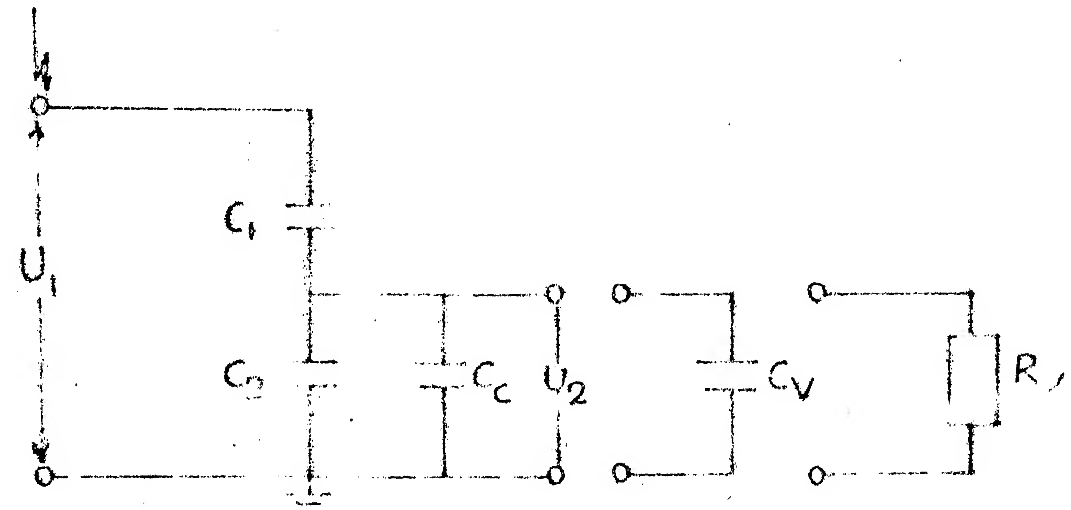


FIG 2.9 MEASUREMENT OF HIGH VOLTAGE WITH CAPACITIVE VOLTAGE DIVIDER

if C_c and $C_v \ll C_2$ if w and R_v are high enough

or $C_1 + C_2 + C_c \gg C_v$ $1 \ll jwR_v(C_1 + C_2 + C_c)$, then

then

$$\frac{U_1}{U_2} = \frac{C_1 + C_2 + C_c}{C_1}$$

further if the cable capacitance C_c is negligible, then

$$\frac{U_1}{U_2} = \frac{C_1 + C_2}{C_1}$$

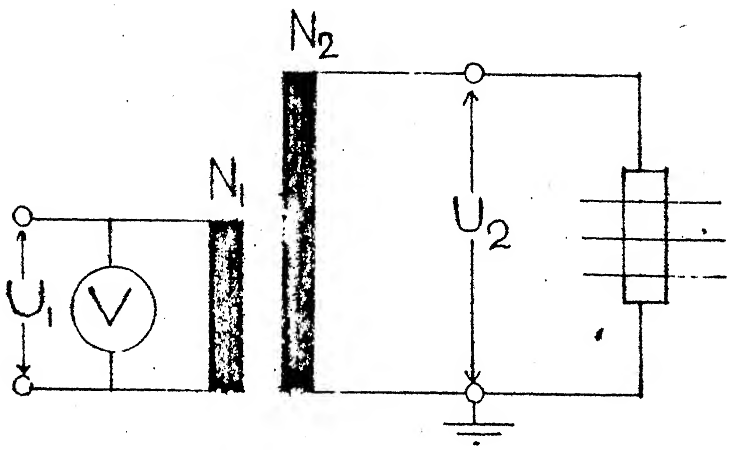
Only in the case when R_v is not large, the voltage division ratio will be affected considerably by the frequency. In all other cases, the division ratio will not vary with frequency. The effect of cable capacitance C_c and capacitance of the measuring instrument C_v must always be considered.

2.3.2.4 Measurement of voltage at the lower voltage winding of testing transformer

The arrangement is shown in Fig. 2.10. The high voltage, applied at test object is given by the relation :

$$U_2 = \frac{n_2}{n_1} U_1$$

This method for the measurement of rms value is useful if the test object charging current is low. In other words if the voltage drop in the test transformer itself is negligible.



U1 _ LOW VOLTAGE
U2 _ HIGH VOLTAGE
N1 _ NUMBER OF TURNS IN THE LOW VOLTAGE
N2 _ NUMBER OF TURNS IN THE HIGH VOLTAGE

FIG.2.10 HIGH VOLTAGE TESTING TRANSFORMER

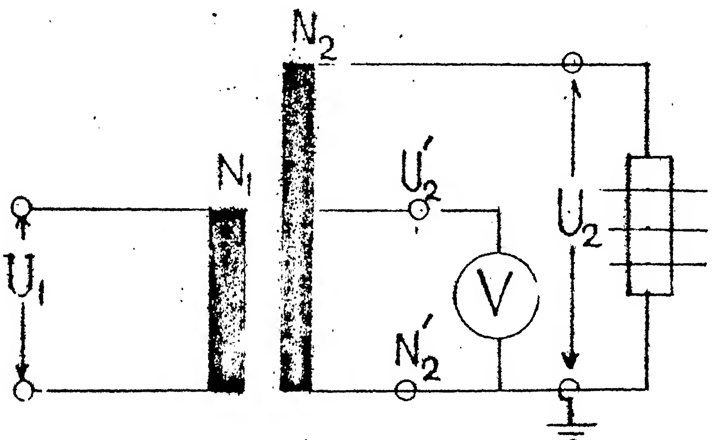


FIG.2.11 MEASUREMENT AT HIGH VOLTAGE WINDING TAPING

2.3.2.5 Measurement of voltage across a definite tapping at the high voltage winding of the testing transformer

The arrangement [2] has been shown in the Fig 2.11. The high voltage applied at the test object U_2 is given by the relation :

$$U_2 = \frac{n_2}{n_2'} U_2'$$

The ratio U_2/U_2' does not vary with the test object charging current but depends upon the frequency, as the distribution of the voltage across the winding is a function of the frequency.

2.3.3 Measurement of Peak Value of the ac Voltage

If the voltage waveform is sinusoidal the knowledge of effective or rms value is sufficient. The peak value can be calculated by multiplying with the factor $\sqrt{2}$.

Due to distortions, a sinusoidal waveform is often not present. This necessitates measurement of peak voltage applied on the test object to know the maximum dielectric strength of the object. Hence a separate peak value instrument is desirable in high voltage applications.

2.3.3.1 Series capacitor voltmeter

When a capacitor is connected to a sinusoidal voltage source, the charging current is $i_o = C \int_o^t v\,dt = jwCV$ where V

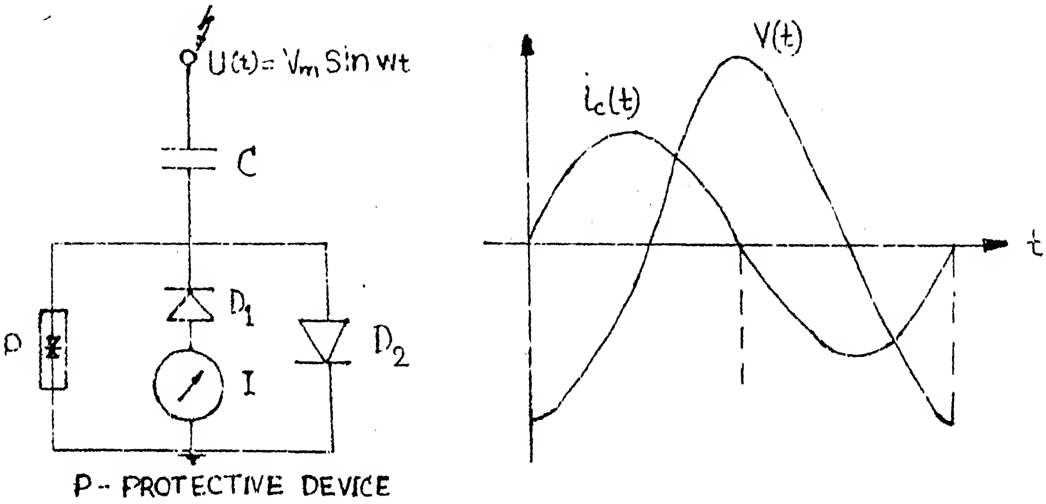


FIG 2.12 PEAK VOLTMETER WITH A SERIES CAPACITOR

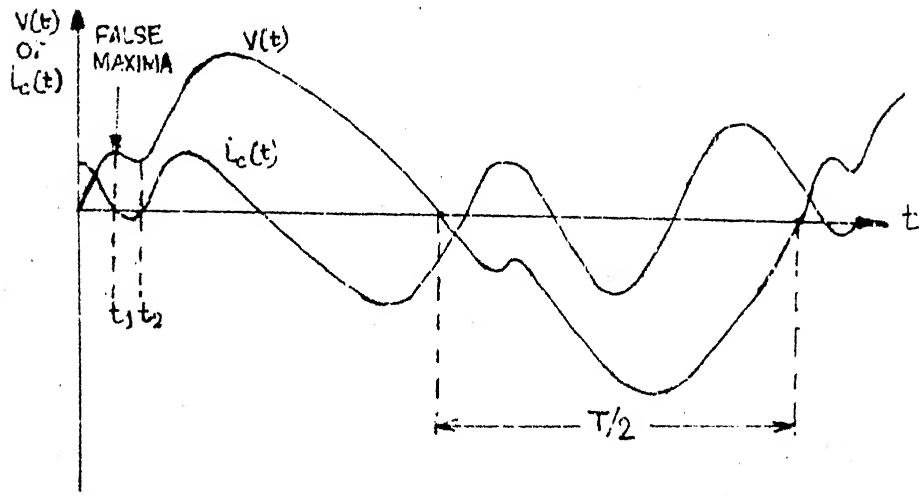


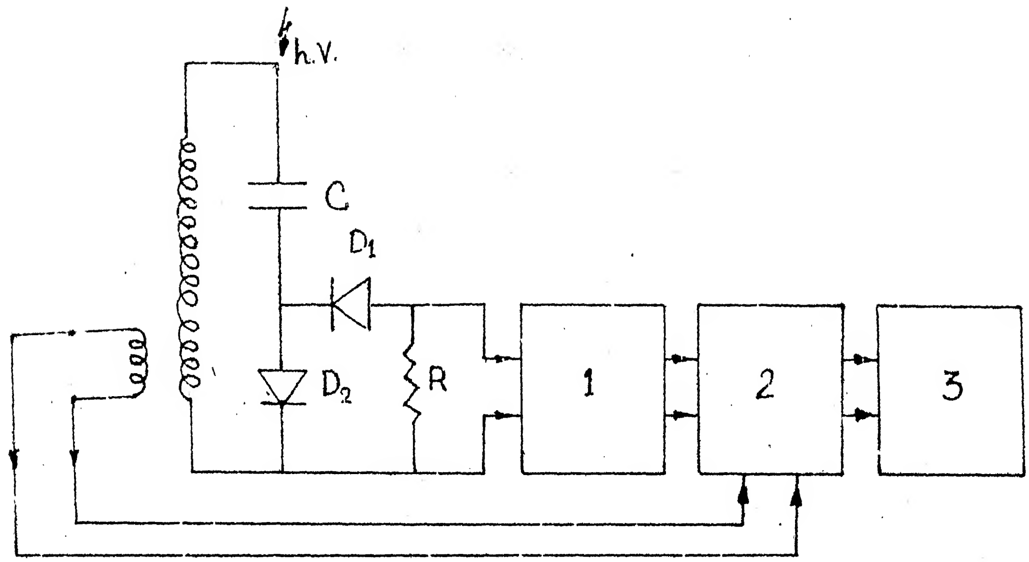
FIG 2.13 VOLTAGE WAVEFORM WITH HARMONIC CONTENTS

is the rms value of the voltage and w is the angular frequency. If a half wave rectifier is used, the arithmetic mean of the rectifier current is proportional to the peak value of the ac voltage. The schematic diagram of the circuit arrangement is shown in Fig. 2.12 [3]. The dc meter reading is proportiona to the peak value of the voltage V_m or

$$V_m = \frac{I}{2\pi fC}$$

where I is the dc current read by the meter and C is the capacitance of the capacitor.

The diode D_1 is used to rectify the ac current in one half cycle while D_2 by passes in other half cycle. This arrangement is suitable only for positive or negative half cycles and hence is valid only when both half cycles are symmetrical and equal. If the voltage waveform exhibit false maxima as shown in Fig. 2.13 [3]. The charging current changes its polarity within one half cycle. Hence, the reverse current flowing during an interval $t_1 - t_2$ will not be included in the mean value. Since there is only one current maxima in any one half cycle, The false maxima is easily spotted out by means of observing the waveform of the charging current through an oscilloscope. This problem can also be overcome by using a resistance R in series with capacitor C such that $CR \lll 1/w$ for



1- VOLTAGE TO FREQUENCY CONVERTER

2- GATE CIRCUIT

3- READ OUT COUNTER (INDICATOR)

FIG 2.14 DIGITAL PEAK VOLTMETER

50 Hz application. The error [3] due to the resistance is

$$\frac{\Delta V}{V} = \frac{V - V_m}{V} = \left(1 - \frac{1}{1+w^2C^2R^2} \right)$$

where, V = actual value, and

V_m = measured value

In determining the error, the actual value of the angular frequency w has to be determined.

A digital peak reading voltmeter is shown in Fig. 2.14. Instead of directly measuring the rectified charging current, a proportional analog voltage signal is derived which is then converted into a proportional medium frequency, f_m. The frequency ratio f_m/f is measured with a gate circuit controlled by a.c. power frequency (f) and a counter that opens for an adjustable number of periods $\Delta t = P/f$. During this interval, the number of pulses, n, is

$$n = f_m \ \Delta t = p. \ \frac{f_m}{f} = 2 \ p \ C \ V_m AR$$

where p is a constant of the instrument and A represents the conversion factor of the ac to dc converter. $A = f_m/(Ri_m)$; i_m is the rectified current through resistance R. An immediate reading of the voltage in kV can be obtained by suitable choice of the parameters R and the number of periods p. The total estimated error in this instrument was less than 0.35% .

Conventional instrument of this type are available with less than 2 % error.

2.3.3.2 Peak voltmeters with potential dividers

In the given circuit given by Davis, Bowdler and Standring [4] shown in Fig. 2.15, a storage capacitor C_s is charged by a capacitance divider to a value proportional to the peak applied voltage. The voltage V_{m_2} across the storage capacitor is measured by an electrostatic voltmeter, with a discharge resistor Rd employed to permit V_{m_2} to decrease in response to reduced V_2 voltage peaks. If R_d is very high-ohmic or is not present during a voltage decrease, the charge could only drain from C_s through insulation resistance and through the diode's reverse resistance, causing considerable error. Hence the time constant R_d C_s of the discharge circuit is usual[illegible] chosen to be about 1 second. Some discharging of C_s will occur between the peak of each cycle even for a long time constant R_d C_s, so that the instrument will indicate a value between the actualcrest voltage and the lowest instantaneous voltage that occur across C_s. This "discharge error " is frequency dependent since the time available for discharge becomes longer with decreasing frequency and thus causes a decrease in the indicated voltage.

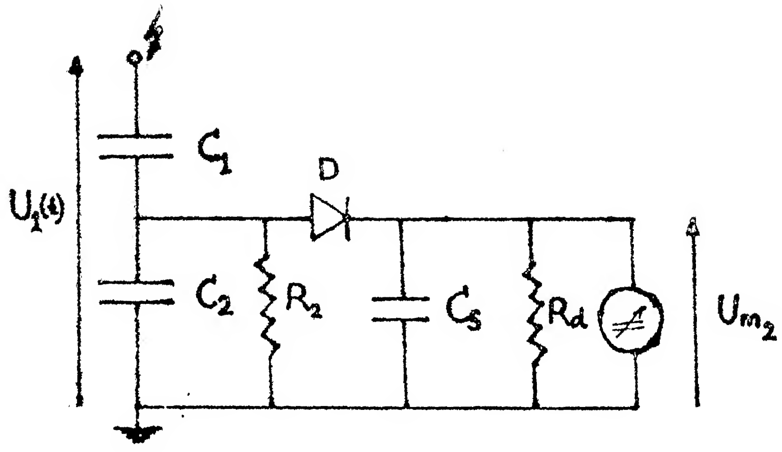


FIG. 2.15

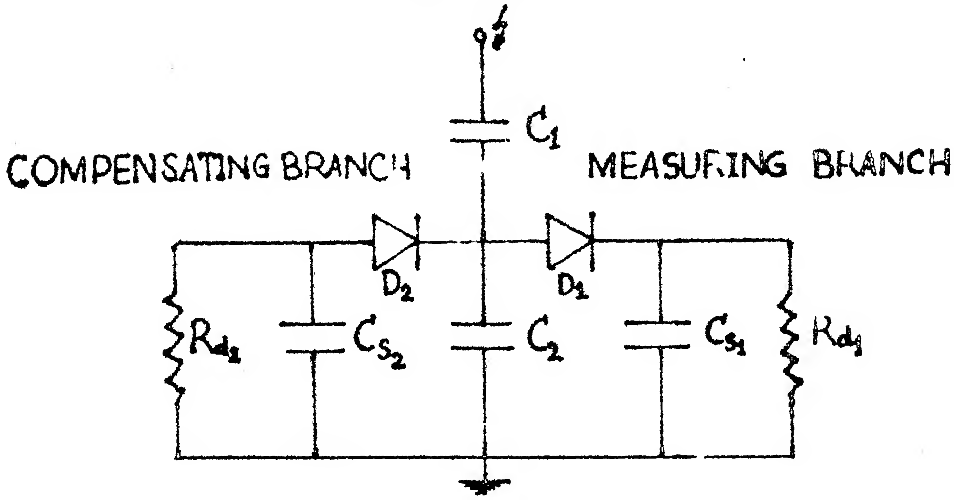


FIG. 2.16

During the time interval within which the storage capacitor is recharged to the actual crest voltage, C_s is paralleled to C_2, increasing the attenuation factor of the capacitive divider. This error is called the recharge error, and it is also frequency dependent. The resistor R_2 paralleled to the low voltage arm of the divider equalizes the charges flowing through the diode and affects the attenuation factor of the divider. The diode's inherent junction capacitance causes a small amount of ac voltage across C_s which is added to the value indicated on the electrostatic voltmeter. In addition, this capacitance is paralleled to the low voltage arm of the divider so that it will influence the attenuation factor. Under these conditions tolerable performance can be achieved if $R_d \gg R_2$ [4]. Because large R_d values will slow down the response to decreasing high voltages, several improvements have been made in the basic circuit (Fig. 2.15).

The two way circuit developed by Rabus [4] consists of two branches that are identical except for a parallel indicating instrument in one of them, Fig. 2.16. Assuming symmetrical high voltage peaks, dc currents drawn from the low voltage arm of the divider during both half waves are equal in amplitude but different in polarity. The dc current in the measuring branch and the compensating branch compensate for each other,

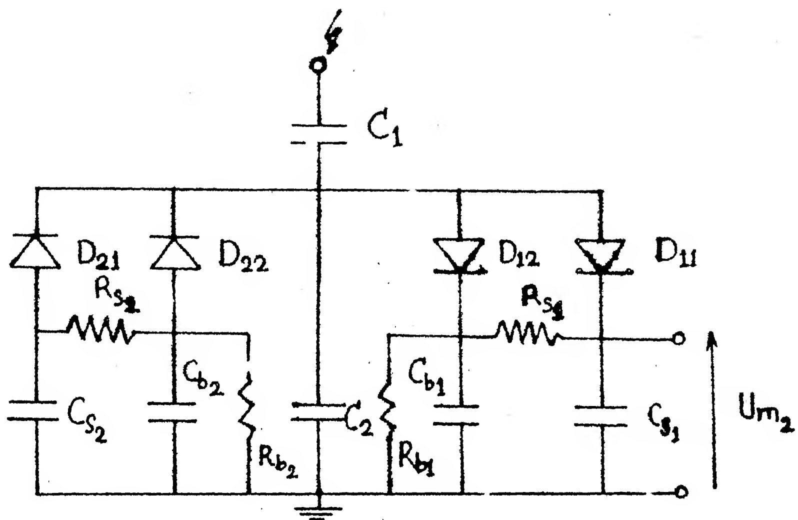


FIG 2.17 TWO WAY BOOSTER CIRCUIT

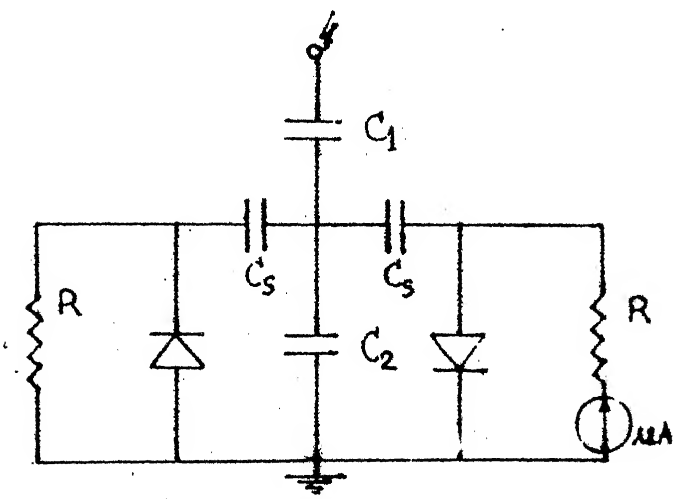


FIG 2.18 PEAK VOLTMETER BY HAEFELY

eliminating the necessity of the resistor R_2 essential in the basic circuit. Although errors associated with R_2 are removed, the discharge error remains. The two-way-booster circuit constitutes a further improvement. Starting with the circuit in Fig. 2.16, this network is completed by two booster branches R_b C_b, Fig. 2.17 [4]. Because the amount of charge in the storage capacitors C_{s_1} and C_{s_2} is maintained from the booster capacitors C_{b_1} and C_{b_2}, their intermittent discharge is minimiz The potential difference across the resistor R_{s_1} and R_{s_2} is sma compared with the amount of voltage across C_{s_1} and C_{s_2}. A decrease in the applied voltage is immediately followed by a similar decrease in the booster circuits, provided their time constant are suitably designed. In contrast, the voltage acros the main storage capacitors discharge rapidly only when the voltage across the booster capacitors has reached a relatively low value. A two way booster circuit permits peak value measurements between 16-2/3 and 100 Hz with an accuracy of ± 1.5 percent.

Peak voltmeter by Haefely

The Haefely peak voltmeter [4] is a modified version of the two way circuit with the storage capacitors and diode interchanged, Fig. 2.18. It exhibits the same discharge and recharge errors as the two way circuit mentioned earlier (Fig. 2.16). Measurement of the average peak value is accomplished by a microammeter using one of the discharge resistor as a series resistor.

Chapter 3

THE USE OF FIBRE OPTICS FOR THE MEASUREMENT OF HIGH VOLTAGE

3.1 INTRODUCTION

The Fibre optic communications, in conjunction with novel optic transducers, may play an important role in the design of measurement techniques for high voltage measurement. The most important aspect about the fibre optic communication is that it can communicate the data from the high potential to the low potential without being susceptible to injected noise or dielectric breakdown. In High Voltage, Extra High Voltage and Ultra High Voltage Systems, Electromagnetic Interference (EMI), Radio frequency interference (RI) and ground mat potential differences cause problems in collecting reliable data using metallic cabling. These data may be bus voltages, currents, load magnitude, status points of circuit breakers or protective relays etc.

The advantages of using fibre optics communication systems in high voltage measurement are following :

(a) the required electrical isolation and freedom from injected noise,

(b) accurate and more reliable data transfer ,and

(c) reduction in overall costs.

Because of the above advantages, fibre optics find a wide applications in Power Systems in communications, measurement and control. In this chapter mainly the use of fibre optics for the measurement has been described.

3.2 MEASUREMENT

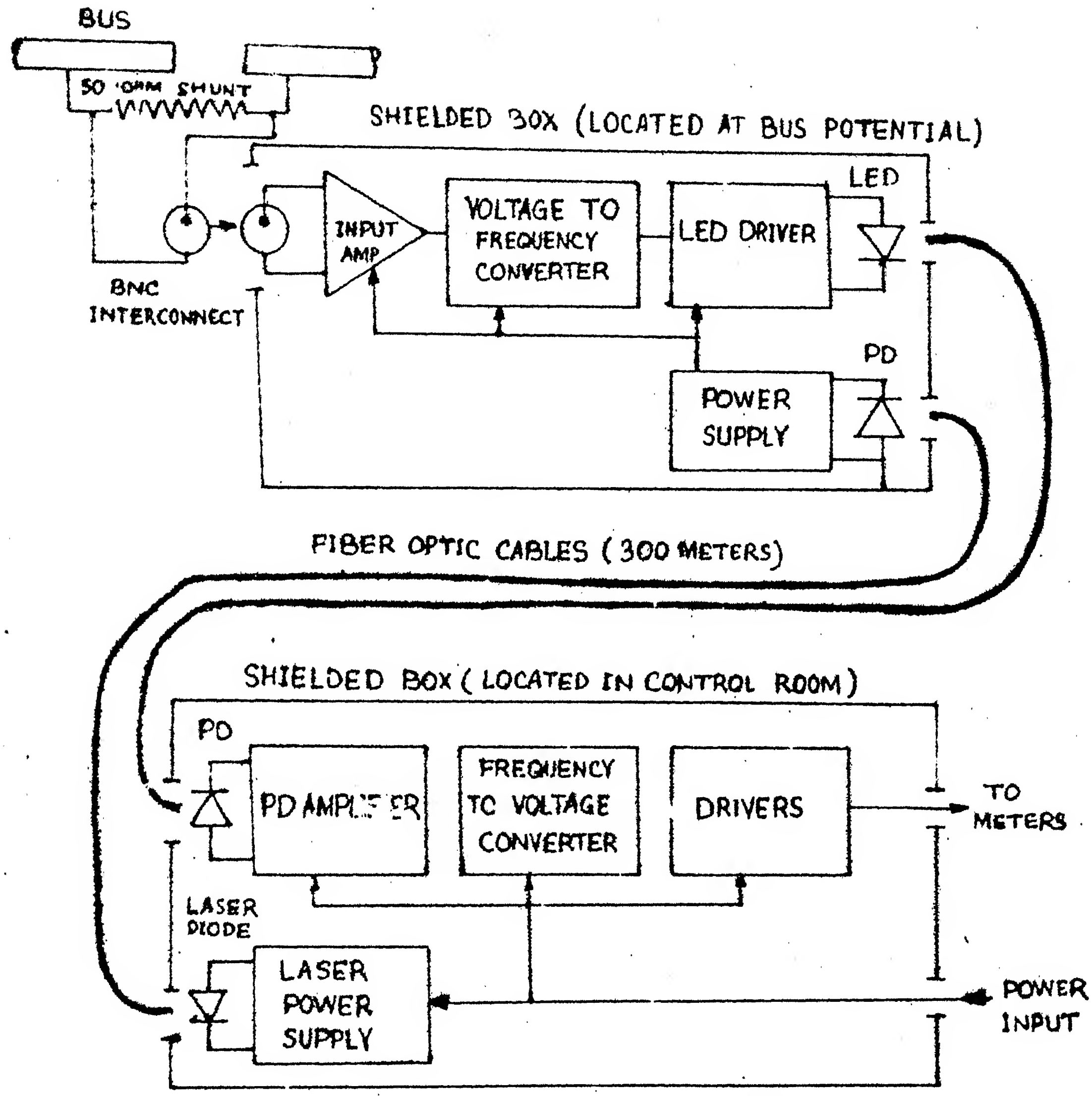
The measurements at high voltage level are done with the help of optical sensors. There are two types of sensors - active and passive. The similarity between them is that in bot systems dielectric optical cables are used between measurement site and control room. The difference is that active devices require a power supply, signal detection, modulation, and an optical source at the measurement site, while a passive sensor employs no electronics at the site and it can be totally dielectric.

3.2.1 Measurement Using Active Sensors

Many attempts have been made to measure the line current by using active devices like LED at the site. Most of the earlier schemes used in- line shunts or current transformers for input power, and A/D conversion [8]. The problem with thes types of schemes were that they required power supply at the site. In some schemes Ultrasonic rod-coupled piezeoelectric devices and solar panel powered systems were used. One of the first systems using optical waveguide was Allis-chalmers [8]

''Traser'' current transformer, This system was tested in 1963 at BPA. It was designed to measure the current on a 230 kV bus. In this scheme a toroidal winding was used to get a small representation of line current, and this small current was used to frequency modulate a Light Emitting Diode (LED). This LED was close-coupled to a rigid, cladded glass rod which was dielectrically connected to a phototransistor and demodulator some six meters away at ground level. The problem with this scheme was that when the line was faulted the power supply, which relied on the bus being energized, could not become useful during that time to enable the modulator to provide adequate information. This scheme was also used for the over current protection of line.

In 1978 westinghouse designed a system for their 500 kV facility, which used a line CT and a special power supply with a start up time of 100 μs [7]. BPA is now testing a system [7] with slightly different approach on the ± 400 kV HVDC Celilo-Sylmar line. This system (Fig. 3.1) uses a shunt with monitor electronics and a LED/fibre link employing voltage to frequency (pulse position modulation) conversion. The unit is powered from the control house with an up-link, high-powered laser diode source. This system offers relief from conventional CT and provides better dynamic current range and frequency response in the measurement, and it will cost less.



BUS
50 OHM SHUNT
SHIELDED BOX (LOCATED AT BUS POTENTIAL)
INPUT AMP
VOLTAGE TO FREQUENCY CONVERTER
LED DRIVER
LED
BNC INTERCONNECT
PD
POWER SUPPLY
FIBER OPTIC CABLES (300 METERS)
SHIELDED BOX (LOCATED IN CONTROL ROOM)
PD
PD AMPLIFIER
FREQUENCY TO VOLTAGE CONVERTER
DRIVERS
TO METERS
LASER DIODE
LASER POWER SUPPLY
POWER INPUT

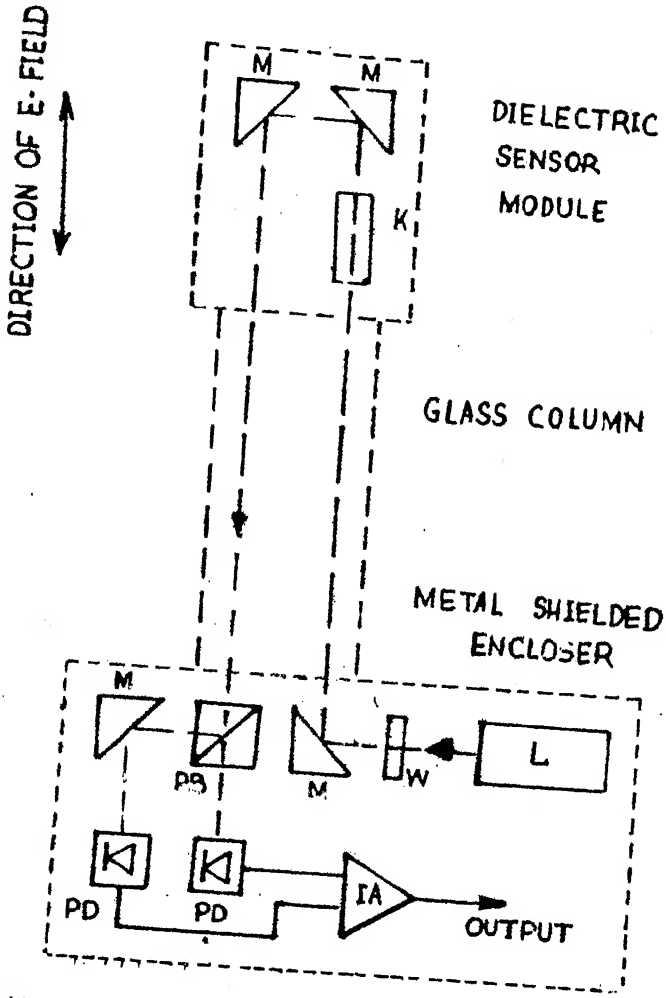
FIG 3.1

The above technique (Fig. 3.1) can be used for the measurement of voltage also. By using a divider (resistive or capacitive), a small representation of bus voltage may be obtained which can be used to frequency modulate the LED. The similar type of LED/fibre link as in the current measurement scheme described above employing voltage to frequency conversion can also be used here. In this scheme though the use of metallic cabling can be eliminated but the potential divider which is bulky and costly remains there.

3.2.2 Measurement Using Passive Sensors

The advantage of using passive devices for the power system measurements is that it does not need any electronic circuits at the measurement site. The entire link outside the control room, including the transducer, could be dielectric, avoiding the need for power supplies, shielding and circuit maintenance. Passive sensors can be installed anywhere and be free from the bonds of component degradation, interference, and large costly support structures [7].

The first prototype of passive device for voltage measurement was designed constructed and tested by BPA in 1975 [8]. This was tested in several 500 kV ac sub-station and one ± 400 kV DC sub-station. The system was a non-contact voltage measurement prototype system which used an electro-optic crystal



K - ACTIVE FIELD SENSITIVE MATERIAL (K*DP)
M - BENDING MIRROR W - WAVE PLATE
PB - POLARIZATION BEAMSPLITTER PD - PHOTODIODE
L - POLARIZED LASER (632Å) IA - INSTRUMENTATION AMPLIFIER

FIG 3.2

interrogated by a laser beam (Fig. 3.2). This prototype needed electronic circuit at the site but the dielectric sensor was completely isolated one meter distant from the high voltage point. The sensor used was K*DP (Deuterated Potassium Dihydrogen Phosphate). Its dynamic optical properties were the result of pockel's effect. It essentially measured the electric field intensity and thus the voltage could be derived. It used a digital fibre optic data link from switch yard to the control room.

Passive Voltage Sensors

Certain crystals, when exposed to an electric field exhibit what is known as the ''Pockel's " effect. In general terms, the electric field causes an optical change in a ''witness " crystal [7] which is interrogated with a polarized light beam. This system (Fig. 3.3) has been developed by BPA.

Specifically, the crystal undergoes a change in the index of refraction of one axis [APPENDIX I]. This is represented by the equation :

$$P_{s,p} = .5\,(P_{in})\,(1 \pm \sin(\gamma))$$

where :

$P_{s,p}$ = optical intensity outputs in both orthogonal planes (s and p)

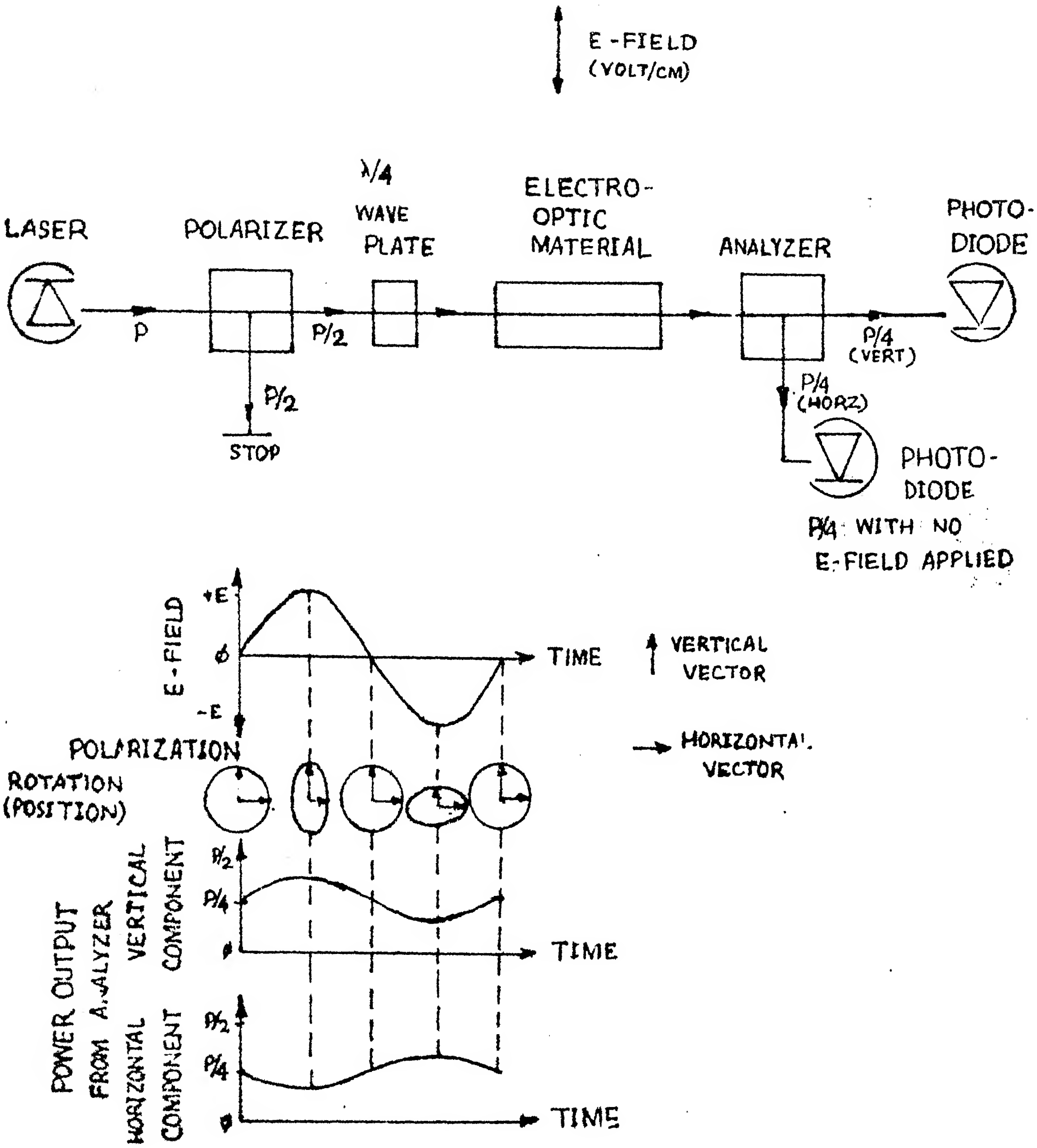


FIG 3.3 POCKELS SENSOR

P_{in} = optical input to the witness crystal.

To account for all system losses,

P_{in} is given by

$$P_{in} = P_{source} \; 10^{\alpha/10}$$

where :

P_{source} = optical input into the system

α = total losses (in dB) in the system

γ = retardation (in radians) due to the impinging electric field E_o

where :

$$\gamma = 2\pi \, L \, n_o^{\,3} \, r_{ij} \, E_o \;\; D/\lambda$$

And :

L = length of crystal (in meters)

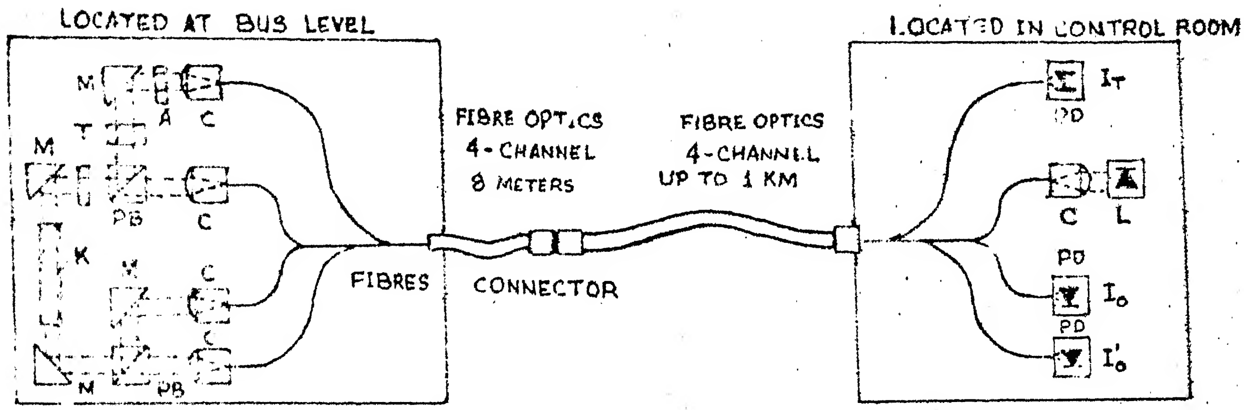
n_o = ordinary index of refraction

r_{ij} = the crystal tensor coefficient, (m/volt)

λ = the wavelength of the interrogation beam (m)

E_o = the electric field outside the crystal (in volts/metre)

D = a depolarization factor [7] required to convert E_o into the field present within the crystal.

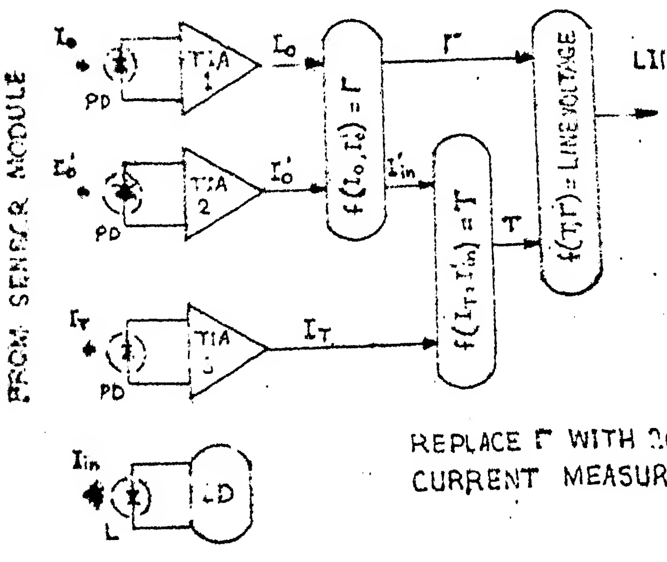


K - ACTIVE FIELD SENSITIVE MATERIAL C - FIBRE OPTIC COUPLER

T - ACTIVE TEMPERATURE SENSITIVE MATERIAL (QUARTZ), L - LASER DIODE (820nm)

I_T - INTENSITY MODULATED TEMPERATURE INFORMATION, I_o AND I'_o - INTENSITY MODULATED FIELD COMPONE

FIG.3.4 OPTICAL SCHEMATIC SHOWING FIELD MEASUREMENT SYSTEM



PD - PHOTO-DIODE (PIN)
LD - LASER DRIVE
TIA - TRANSIMPEDANCE AMPLIFIERS
Γ - E-FIELD STREGTH
Θ - H-FIELD STRENGTH
I_{in} - OPTICAL ENERGY INTO SYSTEM
I'_{in} - $f(I_{in})$

REPLACE Γ WITH Θ FOR LINE CURRENT MEASUREMENT

FIG.3.5

As seen above the optical intensity output is a function of the electric field intensity E_0, from which the voltage can be derived. The above system employs fibre optic waveguide also.

At BPA, another prototype system was designed and constructed in 1980 [8]. For the measurement of voltage, current and temperature using a long (up to 1 KM) low loss fibre. Fig. 3.4 and 3.5 show block diagrams depicting this approach. Temperature measurement is important since E and H-field crystals are affected by ambient temperature and therefore must be corrected by feedback circuits.

Now-a-days several groups are working on integrated optics which would use "microscope slide" like sensors [7] for ultrahigh-speed (1 GHz) A/D converters with $LiNbO_3$ (Lithium Niobate) components. These HV sensors are supposed to be less costly. Another approach which uses polarization optical time domain reflectometry can be used for high voltage measurement too [7].

Chapter 4

DESIGN, FABRICATION, TESTING AND CALIBRATION OF DIGITAL PEAK VOLTMETER

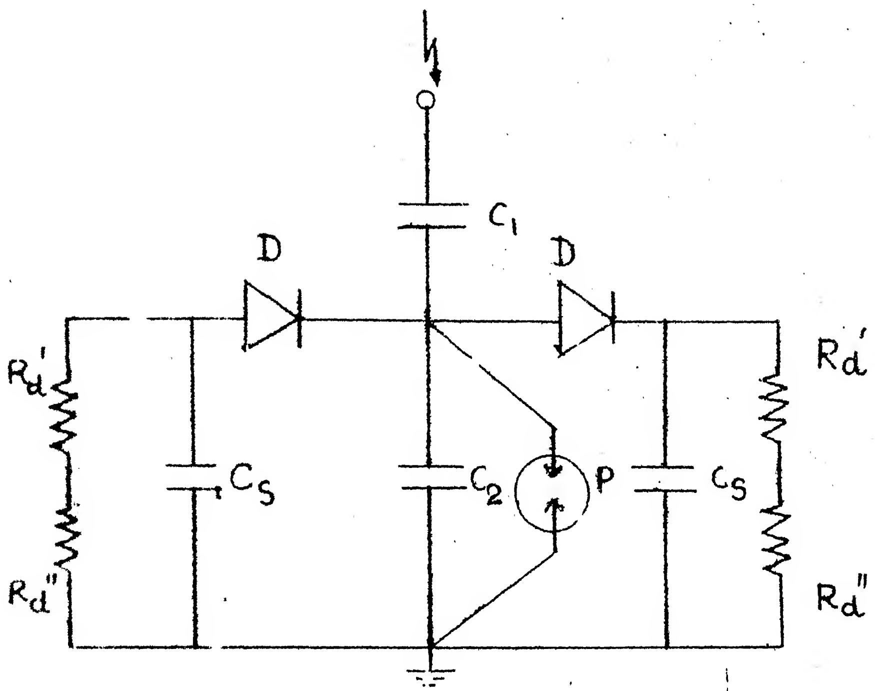
4.1 INTRODUCTION

In chapter 2 [2.2.1 and 2.2.2], the importance of measuring peak value of the voltage and taking the measurement from the secondary side of the testing transformer have been discussed. In this chapter design fabrication, testing and calibration of a Digital Peak Voltmeter has been described. This Peak Voltmeter works on capacitive voltage divider principle [2.3.2.3] and can be used for the measurement of power frequency high voltage from 0-100 kV (rms).

4.2 DESIGN

4.2.1 Design of the Peak Voltage Measuring Circuit

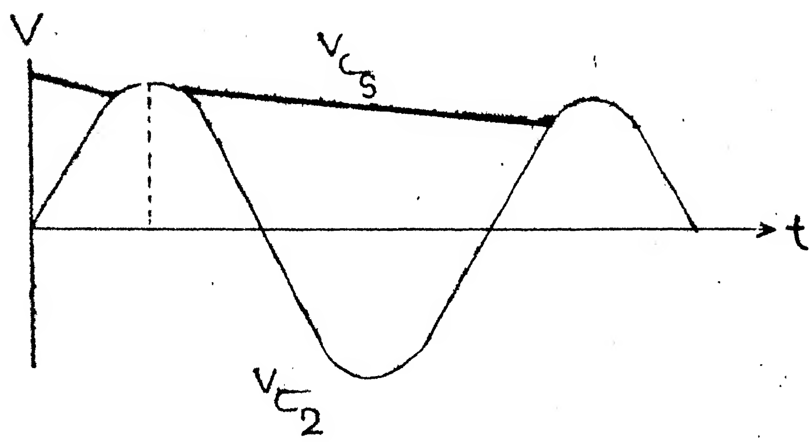
For this instrument a half wave rectifier, peak value measuring circuit with similar compensating branch (Fig. 4.1) has been used. This circuit had been designed by Rabus [3]. This circuit is simple and sufficiently accurate for our purpose. In this circuit, the measuring capacitor C_s is charged to the peak value U_2 of the lower arm voltage $U_2(t)$ of the capacitive voltage divider across the capacitor C_2. The resistor R_d across which the capacitor C_s is discharged, is necessary to ensure an



C_1 - 1.1 nF, 100KV C_2 - 1 µF 600VDC D_10SM3

P_ NEON GLOW TUBE R_d' - 1 MΩ R_d'' - 20 KΩ (VARIABLE)

(a)



(b)

FIG. 4.1

adequate response for the reduction in the applied voltage between the two peaks Fig. 4.1(b). The choice of time constant for this discharge process is determined by the desired response of the measuring arrangement besides the internal resistance of the connected measuring instrument must also be taken into account. As suggested by Kind [5] the time constant is generally chosen to be less than 1 second [5] for such measurement.

$$Rd\ C_S < 1S$$

The other suggested requirement about the time constant is that it should be large compared with the time period T = 1/f of the alternating voltage to be measured, so that the measuring voltage U_m across C_s does not drop significantly between recharging cycles ; $U_m(t)$ has been shown in Fig. 4.1b. Therefore, the appropriate condition can be expressed as [5].

$$R_d\ C_s \gg \frac{1}{f}$$

The compensating branch is just identical to the measuring branch. It prevents dc charging of C_2 due to reverse bias current.

The relation between the peak value of the high voltage and the indicated voltage U_m (measured voltage across C_s) is given by the relation :

$$\hat{U} = \frac{C_1 + C_2}{C_1} \hat{U}_m$$

The cable capacitance C_c has been neglected here as it is very small compared to $(C_1 + C_2)$. The value of the high voltage capacitor in the laboratory is 1.1 nF. Thus the value of the low voltage arm capacitor should be 1 μF for 1000:1 division ratio of the divider. On measuring the actual capacitance of low voltage arm capacitor by an impedance bridge, it was found to be 0.88 μF. Thus the actual division ratio of the capacitor divider works out to be 880:1.

The value of measuring branch resistance R_d should be large in order to avoid the excessive loading of the capacitive divider and prevent distortion of the ideal sinusoidal waveform. The suitable value of this resistance was found out to be 1.02 MΩ (1 MΩ and 20 kΩ in series).

For the measuring branch (C_s) a paper capacitor of suitable rating (1μF, 600 V dc) is provided. The time constant $R_d C_s$ works out to be approximately 1 second as per the required conditions. The compensating branch is identical to the measuring branch.

The capacitance (C_c) of the cable used was measured to be approximately 15 pF with the help of a Schering bridge which is negligibly small for these measurements.

The diode which has been used is 10 SM3. It is a semiconductor diode. The peak inverse voltage is 1000 Volts and current rating is 3 amperes.

The maximum charging current taken by the capacitive divider can be given by wc_1V which works out to be 35 mA (where $c_1 = 1.1nF$ and $V = 100$ kV). Thus the rating of the diode is on the safer side. The low voltage capacitor (c_2) is a paper capacitor.

4.2.2 Hardware Design for Automatic Range Selection

The peak value obtained across the measuring resistance is further attenuated by using measuring resistive branch itself as a resistive voltage divider with approximately 100:1 ratio. The two resistances, which have been used in this branch, are 1.0 MΩ carbon film and 20 kΩ variable wire wound resistances respectively. The Digital panel meter (DPM), which has been used to indicate the measured voltage, can take a maximum input of 2.0 V only. The digital panel meter has ± $3\frac{1}{2}$ digit display and it shows 1999 when the input voltage applied is 2.0 V.

The measured high voltage from 0-100 kV (both rms and peak) has been divided into three ranges to suit the digital display as following :

(I) 0-2 kV : For this range meter displays + 0.000 to +1.999.

(II) 2 kV- 20 kV : The meter displays + 2.00 to + 19.99 for this range and for

(III) 20 kV- 100 kV: range, the meter is selected to display from + 020.0 upto a maximum of 200.0.

From the above, it is clear that ;

(a) DPM can take a maximum of 2.0 Volts,

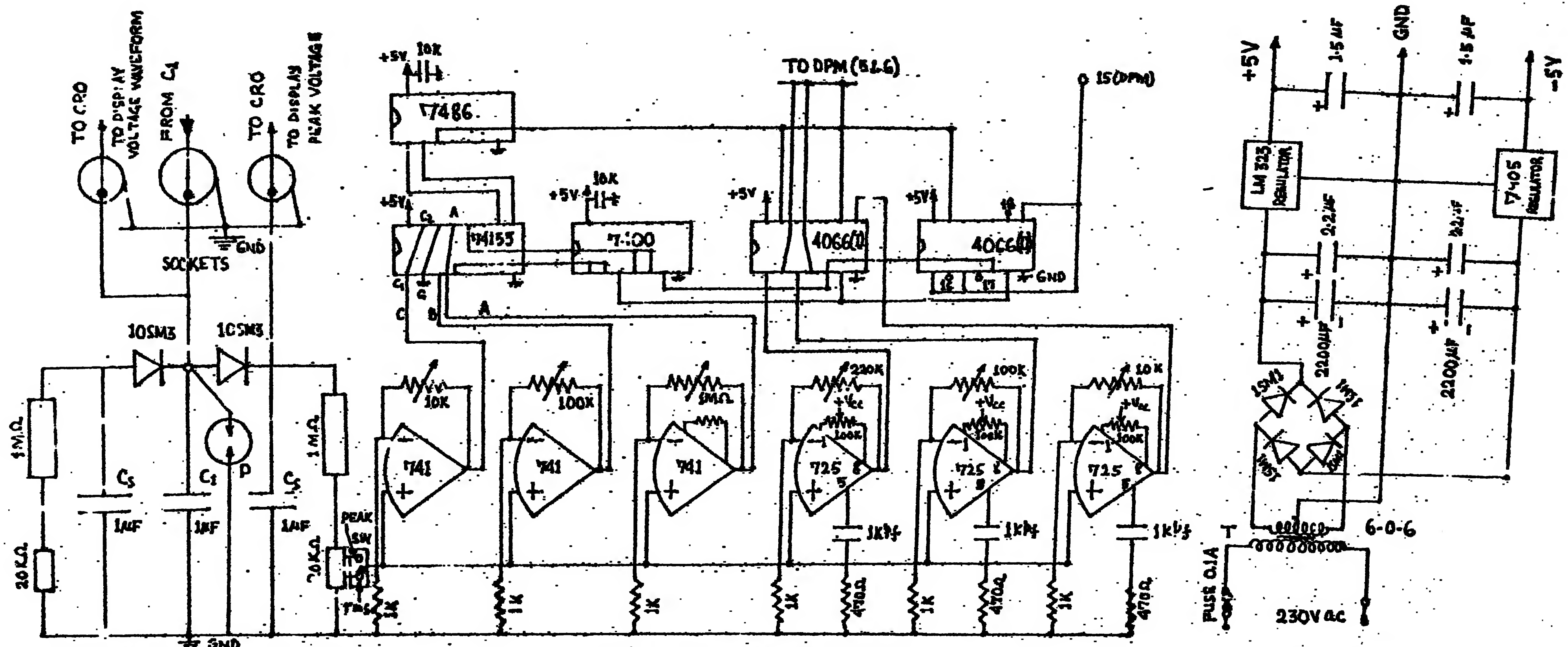
(b) Decimal point in the DPM can be adjusted anywhere depending upon the suitability of the desired range. This is achieved by shorting two of the output terminals of DPM.

The complete circuit diagram has been shown in the Fig. 4.2. The input terminals (pin no. 3) of the operational amplifiers are connected to any one of the two output terminals of the resistive divider desired, with the help of a selective switch. One of the outputs of the divider is to display the peak value of the voltage and the other is to display $1/\sqrt{2}$ times of its value, that is, the rms voltage (may be approximately).

There are six operational amplifiers in the circuit. All of them are in non-inverting mode, which introduces high input impedance in the circuit. This high input impedance prevents loading of the resistive divider R_d and thus provides isolation avoiding any ratio error.

Three of the OP AMPS out of six have been used for range selection. These OP AMPS (741) have different gains. Output terminals of these OP AMPS are connected to the three input terminals of the 3 to 8 line decoder (74155). The input terminals to the decoder are C,B,A. The four output pins of decoder for the four combinations of inputs have been used for the three ranges of selection described above. For 0 kV input, the input to the OP AMP (741) is Ov, Thus C,B,A, all are to low level ($<$ 1.6V).

For range 1 : 0 V to 2 kV (Peak Voltage), the input to OP AMPS will be .002 to .02 V.



PEAK VALUE MEASURING CIRCUIT

AUTOMATIC RANGE SELECTION

POWER SUPPLY

FIG. 4.2

For range II: 2 kV to 20 kV, the input to the OP AMPS will be ,02 V to .2 V, and

For range III: 20 kV to 150 kV ($\leqslant$200 kV) the input will vary from 0.2 V to 1.5 Volts.

Now the input to the decoder (74155) is low when it is less than 1.6 volts, and it is high for the values $\geqslant$1.6 volts. The gain of the OP AMP (741) which were connected to inputs C,B,A of decoder are approx: 8, 80 and 800 respectively.

A table for different ranges of display, input combinations and output levels is given below :

	Range	C	B	A	Output of 74155
I	0 kV	0	0	0	pin 9 (low), pin 10 (high)
I	200V to 2kV	0	0	1	pin 10 (low),pin 9 (high)
II	2kV to 20kV	0	1	1	pin 12 (low)
III	20kV to 150kV	1	1	1	pin 4 (low)

Output pin No. 9 and 10 are connected to inputs of exclusive OR gate (7486) and the output of this is connected to control of switch A of the two analog switches (4066). Pin No. 12 and 4 are inverted (using 7400) and are connected to controls of the switches B and C respectively of both the switches. Out of the two switches (4066), one switch is for connecting the

input of DPM to any one of the three outputs of the OP AMPS (725). And the other 4066 is just for connecting the two terminals of DPM for selecting and displaying the appropriate decimal point.

The three OP AMPS (725) are having gains of the order of 100, 10 and 1. Outputs of these are connected to inputs of switch A,B and C respectively of the analog switch 4066 (I). These switches A,B, and C are for the display ranges I, II and III respectively. For range I, output of OP AMP of gain 100 will be connected to the input of DPM. Now, if the peak value is 1 kV then the input to the OP AMP will be .01 volts and DPM will display + 1.000. Similarly it works for the other ranges.

The other three switches of 4066 (II) are for displaying the appropriate decimal point. The switch A shorts the terminal 15 and 16 of DPM (according to the DPM manual) and displays the decimal point after the left most digit (range I). Switch B shorts the terminals 15 and 17 and displays decimal point after second digit from the left (range II). Switch C shorts the terminals 15 and 18 to display decimal point before rightmost digit (range III).

4.2.3 Power Supply

One of the most important part required for the instrument is an appropriate power supply for the circuit. A dual power supply (+5V and -5V) is needed for the circuit described.

A centre tapped transformer (6-0-6V,2A) has been chosen for the power supply. The diode (1 SM1) bridge circuit is used to rectify the ac voltage. Two capacitors of 2200 μF have been used as filters for the positive and negative power supply. For regulated positive voltage, a 3-pin regulator (LM-323, +5V, 3A) has been employed whereas for regulated negative power supply, a 3-pin regulator (μA 7905, -5V) has been used. Tantalum capacitors are connected at the output to improve the transient response of the regulator. The circuit diagram of the power supply is shown in Fig. 4.2.

4.3 PROTECTION

It is very important that an instrument is provided with adequate protection for its long term satisfactory performance. The peak voltmeter developed may be exposed to different over voltages due to high voltage flashover or due to inadequate earth connection. In view of the expected hazards the following protections are provided in the instrument,

4.3.1 Earthing

It is very important that an instrument must be properly earthed whereverrequired. The casing of the instrument must be properly earthed to prevent from any severe shock in case of a fault. The cause of the danger may be due to following :

(a) If the coaxial cable, which connects the lower end of high voltage capacitor to the lower voltage arm capacitor is not connected properly, it may lead to isolated condition of the HV capacitor due to which the lower arm of the HV capacitor may acquire high voltage (of the order of applied voltage). This may give rise to a dangerous condition and failure of the coaxial cable. If the casing of the instrument is not properly earthed, it may also acquire high voltage.

(b) If the lower end of the low voltage arm of the capacitor is not connected to earth properly, in that case too the above situation may arise.

4.3.2 Overvoltage Protection

Under the condition explained above or due to some other causes e.g. the failure of high voltage capacitor etc., high voltage may develope and damage the circuit elements endangering the personnel working with the instrument. To protect the instrument from such faults, a neon glow tube Fig. 4.1, has been connected across the low voltage capacitor C_2. This will not allow the voltage at cable end to increase more than 120 volts as the neon bulb glows when voltage across it is more than 120 volts and shorts the circuit. This was tested in the lab separately.

4.3.3 Fuse Protection for Power Supply

One fuse of 0.1A has also been provided to protect the power supply against any short circuit etc.. This has been connected at the input side of the transformer. For normal operation, the input current will be much smaller than 0.1 Amp.

4.4 TESTING

Testing of the fabricated instrument was done to ensure if the switching over voltage produced due to breakdown of insulation does any harm to the peak value measuring instrument.

For this test, a needle plane electrode system was used (Fig. 4.3). The needle was applied the high voltage and other electrode (plane) was grounded. Digital peak voltmeter and oscilloscope were connected to measure the voltage and to see the waveform of the applied voltage. The high voltage was increased gradually and after a certain voltage level the breakdown between the two electrodes took place which operated the relay and tripped the circuit breaker on the low voltage side of the transformer. Extinction of arc between the electrode may cause an overvoltage which will travel to the divider. However, there was no effect of such overvoltage observed on the voltmeter and oscilloscope. It shows that the surge arresters used within the transformer on the primary as well as

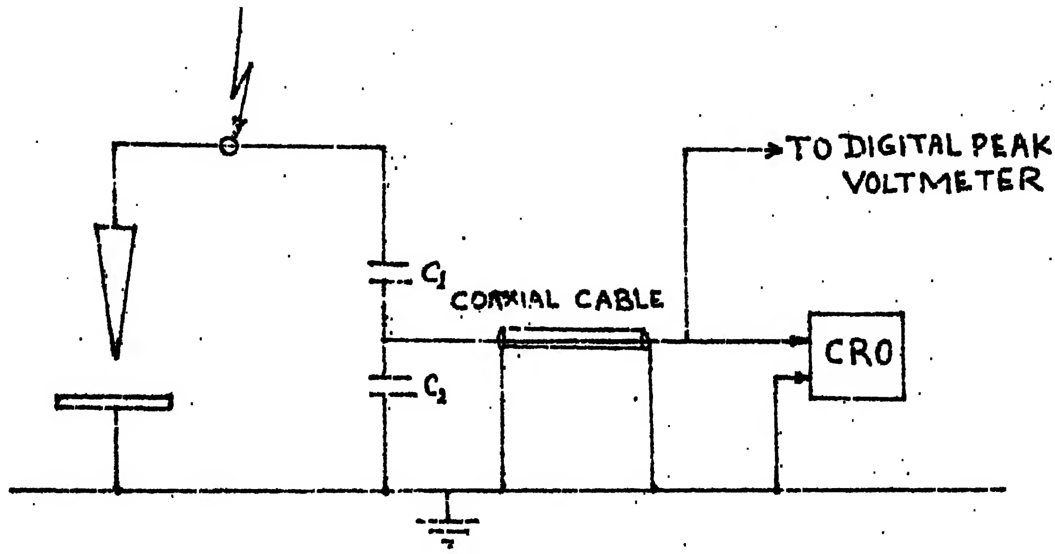
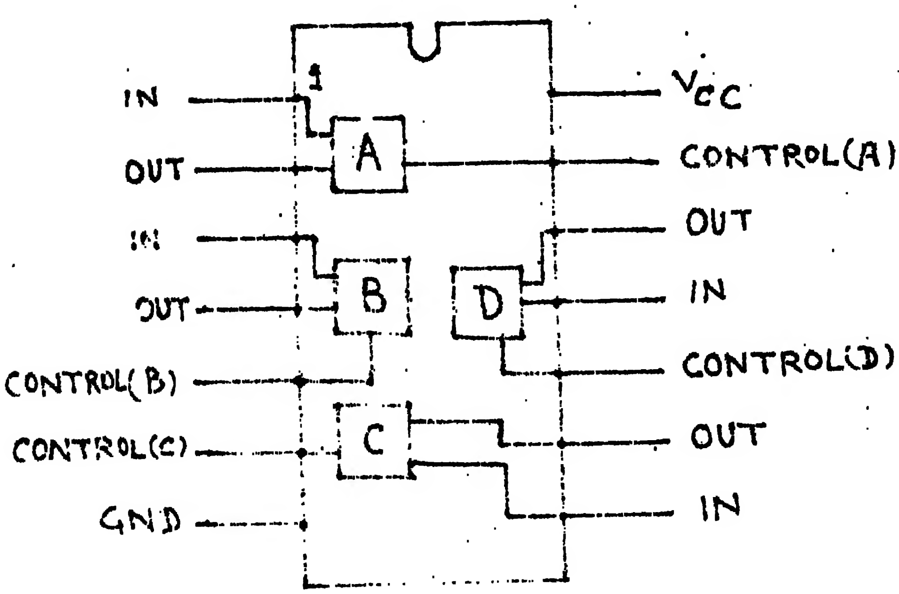


FIG.4.3. TESTING



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secondary side are taking good care of such switching surges. Thus one may infer that the instrument is capable of withstanding any such switching overvoltages.

4.5 CALIBRATION

The instrument has been calibrated with the help of a standard capacitive divider and voltmeter unit [Capacitive Voltage Divider used with 410B Vacuum Tube Voltmeter]. This capacitive divider has 1000.1 ratio and can measure maximum 25 kV ac. The frequency range is 20 Hz to 20 MHz. The instrument could be calibrated upto 25 kV only by adjusting the gain of OP AMPS (725). For higher voltage range, it is taken for granted that the instrument will continue to give accurate reading.

4.6 APPLICATION AND UTILITY

A Digital Peak Voltmeter is an extremely useful instrument for high voltage testing and R and D. laboratories for an accurate and continuous measurement of the high voltage. Besides displaying the peak voltage, applied at the test object, it can also display the effective or rms value (approximate) of the voltage. The instrument is also provided with two sockets at appropriate position in order to display the applied ac voltage waveform and its peak value on the oscilloscope screen separately.

4.7 PERFORMANCE

The performance of the Digital peak voltmeter was found to be satisfactory.

In range I (0-2 kV) the display was found to be instable, so the range II had to be extended to begin from 0 kV by adjusting the gain of one of the OP AMP (741) [OP AMP which had the gain of 80 earlier]. In the range I, offset voltage of the OP AMP (725) was found to be instable. That may be the cause of output of the OP AMP (725) to be instable.

The accuracy in the range I (0-20 kV) works out to be between 0.8% and .045%, and

in the range II (20 kV - 150 kV)

between 0.5% and 0.1%.

Chapter 5

CONCLUSION

For an accurate and continuous measurement of high voltage, it is very important to measure the peak value of the high voltage. This even more important for measurement of output voltage of a testing transformer in HV laboratory with large capacitive loads.

Measurement of peak value of the HV voltage with the help of a HV capacitive voltage divider linked to the peak voltmeter instrument with a coaxial cable is practiced in modern HV laboratories. The peak voltmeter instruments used earlier were analog but with the advancement in digital measurement techniques, such digital instruments are available abroad. A digital peak voltmeter has been developed using a half wave rectifier circuit with similar compensating circuit. Such an instrument is yet not available commercially in India. With the availability of capacitive voltage dividers indigenously, it is expected that the demand for digital peak voltmeter will increase.

The instrument developed can measure the peak value of the high voltage from 0 to 200 kV and rms value of the voltage applied. However, the rms value measured is accurate only when

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APPENDIX I

POCKELS EFFECT

The linear electrooptic (or pockels) effect refers to a change in relative optical dielectric impermeability B_{ij} proportional to an applied electric field E_k, whose highest frequencies are below the lattice resonance of a crystal.

The change in $1/n^2$ with application of field where n is the refractive index. $1/n^2$ can be written as

$$\frac{1}{n^2} = \frac{1}{n_o^2} + rE + RE^2$$

Where r and R are the linear and quadratic electrooptic coefficients, respectively. The coefficients in above equation are for a direct (primary) effect which is independent of crystal strain. In addition if the crystal develops macroscopic strain under the influence of field, there will be a change in index through the electrooptic effect.